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Modern Boiler Designs for Firing Indian and Southeast Asian Coals

by:

Angelos Kokkinos
VP, Engineering
Riley Power Inc.

Dr. Dave Kalmanovitch
Chief Metallurgist
Riley Power Inc.

Kevin Toupin
Manager, Boiler Equipment & Design
Riley Power Inc.

V. Kannan
Cethar Vessels Ltd.
Tiruchi, India

Riley Power Inc.
5 Neponset Street
Worcester, Massachusetts 01606
www.babcockpower.com

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MODERN BOILER DESIGNS FOR FIRING INDIAN AND SOUTHEAST ASIAN COALS

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A. Kokkinos
Dr. D. Kalmanovitch,
K. Toupin
Riley Power Inc.
A Babcock Power Inc. company
Worcester, MA USA

V. Kannan
Cethar Vessels Ltd
Tiruchi, India

ABSTRACT

In 1937 at a meeting of the American Society of Mechanical Engineers, Henry Kreisinger, a pioneer in coal combustion, indicated "that the main reasons why pulverized coal firing is favored over other methods of burning coal is because pulverized coal burns like gas and, therefore, fires are easily lighted and controlled. Almost any kind of coal can be reduced to powder and burned like gas. A change in coal upsets the operation of a pulverized-coal plant to a much smaller degree than it does a stoker-fired plant. Pulverized-coal furnaces can be readily adapted to burn like gas, and in that respect are capable of burning almost any fuel which is used for making steam."

Today, over 70 years later, pulverized coal is dominating the fossil fuel utility boiler power generation market with major reasons for its success being its abundance and hence lower price, and capability to design boilers that can burn a variety of coal ranging from anthracite to lignite. Although this current day experience confirms Henry Kreisinger's pioneering vision, it was not accomplished without careful consideration of the coal properties on boiler design and operation. This is further complicated by the need of coal plant operators to reduce operating costs due to the increased competition that they face. Fuel costs represent a significant portion (approximately 60%) of the overall costs of operating a modern powerplant.

The paper provides a summary of important coal properties and their impact on a boiler design with particular emphasis on Southeast Asia (Indian, Indonesian) coals.

Impact of Mineral Matter on Boiler Design

A major impact on the design of pulverized coal fired boilers is the predicted behavior of the inorganic matter embedded in the coal. The high combustion temperatures and resulting high gas temperatures within the boiler result in the creation of ash. This ash is then deposited on various heat transfer surfaces of the boiler in both the radiant (slagging) and the convective (fouling) sections of the boiler. The resulting slagging and fouling create operational as well as performance problems, such as reduced heat transfer, increased gas temperatures, reduced operating efficiency, loss of power generation and increased boiler maintenance (slag falls, etc.). These effects can have a significant impact on the overall economics of the power plant and, as a result, properties of the coal and its ash, in particular, need to be taken into account in developing the design of the boiler.

The ash is formed from the presence of non-combustible mineral matter in the coal (e.g., quartz, clays, sulfides, oxides, etc.) in various shapes, sizes, and associations, as well as inorganic species that are associated/bonded with the carbonaceous matrix of the coal. As the coal has formed over the millennia, its non-combustible mineral matter composition assumes the characteristics of the earth's crust. As such, the mineral matter composition is very much dependent on the local conditions. Therefore, coal mineralogy of Indian and Indonesian coals can be very much different than that found in Eastern US bituminous coals from the Appalachian Basin.

Despite the complexity of the mineralogy, methods have been developed and adapted that can predict the behavior of the ash and its impact on boiler design and operation. This impact can be derived from both chemical analysis and empirical tests. The analysis of the coal ash lists, on a weight percent basis, the elements of the ash such as silica (SiO_2), alumina (Al_2O_3), ferric oxide (Fe_2O_3), lime (CaO), etc. From this analysis, some simplified approaches have been developed in deriving ash behavior in terms of slag deposition and flow. These included:

* Silica/Alumina ratio
* Base/Acid ratio
* Iron/calcium ratio
* Ash fusion temperatures
* Viscosity/temperature relationship
* Alkali levels

Such empirically derived norms have been developed mainly for US and Northern European coal and to a lesser extent for Western US sub-bituminous coals. These techniques have been used to establish the basic design criteria for boilers however they should be used with caution since the basic assumption is that coal particles entering the furnace are chemically homogeneous. Furthermore some of these basic criteria were originally developed for stoker firing and they may not therefore represent the true behavior of the ash during pulverized coal combustion.

Over the past 25 - 30 years, it has been observed that the ash behavior due to the application of "new coals" (e.g., Powder River Basin, Dakota lignite, Indian, Indonesian, etc.) in boilers is different from the behavior predicted using the "standard" methods shown above. These have resulted in the development of new methods to better predict their performance. Some of the problems not predicted by the standard methods and the resulting methodology/research developed are summarized as follows:

* Lignite fouling due to high alkali/alkaline earth species lead to the development of chemical fractionation techniques that measure the organically bound sodium, potassium, magnesium, and calcium

* Convective section deposition of Calcium Sulfate lead to the need to characterize the origin and behavior of calcium species in coals

* Reflective ash on the furnace waterwall causing increased furnace exit gas temperatures lead to research on the formation of fume material and the condensation/thermophoresis of select species in the furnace

* Corrosion (fireside) by ash deposits lead to the development of methods to follow reaction pathways within a deposit that result in the formation of phases that disrupt the protective scale on the tubes

* Erosion (fireside) by the fly ash leads to the development of mineralogical techniques to examine and measure the size and shape of potential erosive components such as quartz. These same techniques also resulted in the development of erosion resistant materials for the fuel preparation and transportation system (pulverizer)

In concert with the above were the development of models of ash formation, deposition, erosion, corrosion and the development of strength that included mechanisms of thermal degradation coalescence, entrainment, flow, melting, crystallization, and the viscosity of specific and bulk molten phases.

It is becoming evident therefore that true and accurate predictions of coal and ash behavior and their impact on boiler design and operation are necessary. When dealing with a coal that fits a known geology and mineralogy/chemistry and fuel properties, reliable prediction and design considerations can be made using past experience. However, for coals that fall outside the normal experience and when less conservative approaches are required, it is necessary to combine not only known behaviors but also a more fundamental approach. This combined approach incorporates not only empirical knowledge but also the science of geology, mineralogy, chemistry and physics along with disciplines of mechanical and chemical engineering.

Riley Power Inc., a Babcock Power Inc. company, has developed a state of the art approach1 based on the fundamental approach to ash deposition that characterizes the coal minerals and entrained fly ash species to model the deposition and development of design criteria of boiler design for these coals. This approach also incorporates known empirical data that has been gathered through many years of unit operation. The use of advanced techniques, such as Computer Controlled Scanning Electron Microscopy (CCSEM)2,3, help to determine the size, shape, association and chemical composition of the minerals and fly ash particles. Chemical fractionation to establish the elements bound to the coal matrix and Scanning Electron Microscopy Point Count (SEMPC)2,3 to determine the phase assemblage of ash streams and deposits. Scanning Electron Microscopy (SEM) is used to determine the morphology of the ash and the deposits to establish the specific mechanisms of deposit formation and growth. The data from these techniques are used in combination with standard and bulk techniques (chemical composition, ash fusion temperatures, etc.) to produce a more accurate prediction an assessment of a given fuel on a boiler system.

Such a fundamental approach and process allows the determination of key design parameters based on the true ash characteristics and do not rely on generic and bulk properties. This approach allows for the combination of traditional methods, along with advanced techniques, while incorporating empirically derived experience that allows for properly designing the boiler for optimum performance and reliable operation.

Effect of Coal Analysis on Boiler Design

As indicated above, the overall physical and chemical composition of the coal, along with individual constituents/properties, play an important role in determining the basic design of a boiler. Below is a synopsis of the important factors and their effect on boiler design.

Table 1

Effect of Coal Properties on Boiler Design

Fuel Parameter	What does it Affect?	Impact on Design/Equipment
Ultimate Analysis	Air & flue gas flow rates, draft loss	Flue gas flow area — tube spacing
Heating Value	Boiler efficiency, heat rate	Duct and flue gas equipment sizing Fan sizing/margins
Moisture content	Air & flue gas flow rates, draft loss	Pulverizer capacity/sizing
	Boiler efficiency, heat rate	Pulverizer air flow & temperature requirements
	Coal drying requirements	
Sulfur content	SO_2/SO_3 production	Potential back-pass corrosion
	Acid dew point temperature	FDG sizing
Ash content	Ash production	Ash removal equipment
	Ash erosion	Flue gas area/velocity
Ash temperatures/properties	Waterwall slagging potential	Sootblower location, type
	Furnace efficiency/absorption potential	Furnace size
		Radiant surface area
Ash mineral properties	Convective section fouling potential	Tube spacing requirements
		Sootblower application

Over the past fifty years, most of the units operating in India have been firing domestic coals. Global economics, however, along with environmental concerns and a reduction in domestic coal reserves, have made it necessary for operators to explore alternative coal supplies. Southeast Asia (Indonesian) and Australian coals have been proposed as alternatives due to their proximity and costs.

Table 2 below provides a comparison of the key properties of the Indian and Indonesian coals. As a comparison, a popular US coal from the Powder River Basin (PRB) of Wyoming is also included.

Table 2

Comparison of the Basic Properties of Indonesian, Indian, and US Powder River Basin Coals

	Indian	Indonesian	US PRB
Total Moisture, %	5 - 10	25 - 35	20 - 30
Ash, %	35 - 45	3 - 6	3 - 6
Fixed Carbon, %	20 - 30	25 - 40	25 - 40
Volatile Matter, %	20 - 30	25 - 40	25 - 40
Sulfur, %	0.5 - 4.0	0.1 - 2.0	0.4 - 0.8
HGI	55 - 65	50 - 65	50 - 60
HHV, kcal/kg	3,000 - 4,000	3,500 - 4,500	4,500 - 5,000

Examining the basic properties of these coals reveal that care needs to be taken in the basic design of the boiler for each one of those coals. At first glance the fuel preparation system along with the flue gas pass would have to be substantially different. The pulverizers, for example, would have to be sized at a larger capacity to account for the lower heating values of the Indonesian, Indian and US coals as compared to typical bituminous coals (e.g., Australian). The high amount of ash content of the Indian coal would require the use of wear resistant materials to maintain pulverizer reliability. Pulverizer selection (i.e., vertical spindle vs ball tube) also becomes important depending on coal selection and maintenance requirements. The size of primary air fans and air preheater is dependent of coal moisture content.

A significant amount of effort has been undertaken in developing wear resistant materials and techniques to allow for increased reliability of the equipment that comes in to contact with the pulverized coal. Figure 1 shows an example of wear resistant material laboratory testing.

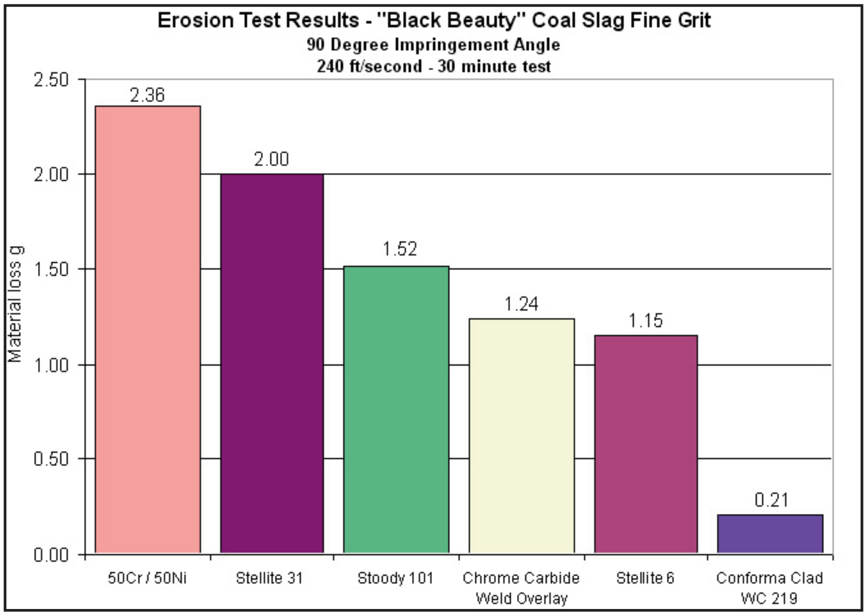

Figure 1: Laboratory test results of abrasion resistant materials

Proprietary techniques such as the Clad-Tech weld overlay process have resulted in improving pulverizer roll life by over 75% over typical wear resistant materials.

Figure 2 is a photograph of the process that impregnates the pulverizer with Tungsten Carbide (WC) particles thereby improving its wear life.

Figure 2: Photograph of roll with Clad-Tech process

Further examination and analysis of the coal and ash chemical properties is used to establish the basic design of the furnace and its convective heat transfer section and surfaces. Indian coals are characterized by their high ash content, high alumina (Al_2O_3) and silica (SiO_2) indicating that additional spacing in the convective section along with lower flue gas velocities would be required. The main furnace design for Indian coals needs to be larger to allow for the increased amounts of ash and should also be equipped with an increased number of sootblowers. Special coatings on the leading tubes are used for added protection against erosion (see Figure 3).


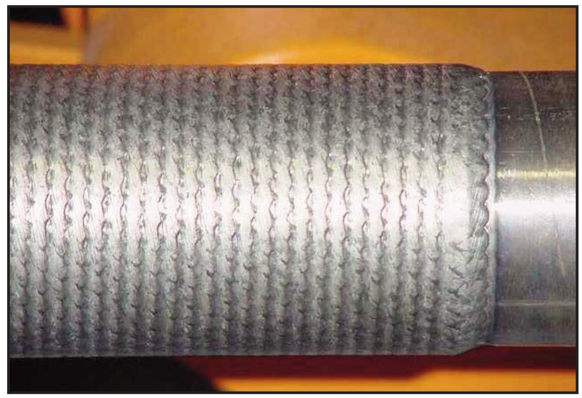

Figure 3: Weld overlay coating of boiler convective section tubes

Indonesian coals on the other hand, although having lower ash content, have characteristics that could be worrisome if not evaluated properly. The ash fusion temperatures are low and, coupled with the high alkali (Na, K) content along with low fusion temperatures, indicate a propensity for convective section fouling. This, coupled with their high moisture which generates a higher volume of flue gas, requires the convective section to be designed with larger spacing between tubes and with lower velocities. The lower furnace design, however, needs to be carefully thought out. The Indonesian coal ash has lower fusion temperatures and, as such, tends to be "sticky" on the furnace walls creating a coating that is insulating in nature. Its high alkaline earth content (Ca, Mg) also tends to make the deposits reflective of the furnace radiation further reducing the heat transfer rates. As a result, furnace size could be increased by as much of 25% as compared to a bituminous coal fired unit.

CONCLUSIONS

* The overall physical and chemical composition of the coal play an important role in determining the basic design of the boiler
* Today's economics dictate the need for flexibility in boiler design so that the Power Plant Owners can have the freedom to switch coal
* Riley Power in conjunction with Cethar Vessels Limited, Riley's exclusive Indian Licensee, have the experience and technology to characterize coals and assist in the design of modern steam generators that allow the use and switching of difficult coals containing high ash or constituents that can be troublesome

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